RESEARCH AND DEVELOPMENT STUDY ON IMPROVEMENT OF ADVANCED RADIATION-RESISTANT MODULARIZATION TECHNIQUES

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FINAL REPORT

Period Covered

15 May 1964 through 30 November 1964

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt, Maryland

Contract NAS5-3812

Prepared by

RADIO CORPORATION OF AMERICA
Special Electronic Components and Devices
Direct Energy Conversion Department
Mountaintop, Pennsylvania

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ABSTRACT

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Wrap-around solar cells (both contacts on the back) have been successfully fabricated. These cells have a 5% greater active area than cells of the standard construction.

Twenty 10 cell modules were constructed by sweating wrap-around cells to printed circuit boards. The resulting modules showed an overall increase in output power of 4% compared to a Nimbus type 10 cell module, which is made of standard solar cells.

The demonstration of the feasibility of fabricating assemblies on a dielectric substrate with printed circuit interconnections can be extrapolated to the fabrication of large arrays, possibly square feet, as a single entity.

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RESEARCH AND DEVELOPMENT STUDY ON IMPROVEMENT OF ADVANCED RADIATION-RESISTANT MODULARIZATION TECHNIQUES

FINAL REPORT
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I. INTRODUCTION

The objective of this contract was the development of a wrap-around solar cell (both contacts on the non-active side) and to fabricate 20 modular assemblies of 10 cells each with the wrap-around cell. The modules were fabricated on a thin dielectric material containing printed circuit connections. The solar cells were jigged in position above the printed circuit and sweated to the electrical connections, using solder pre-forms. The advantages expected of this construction technique are:

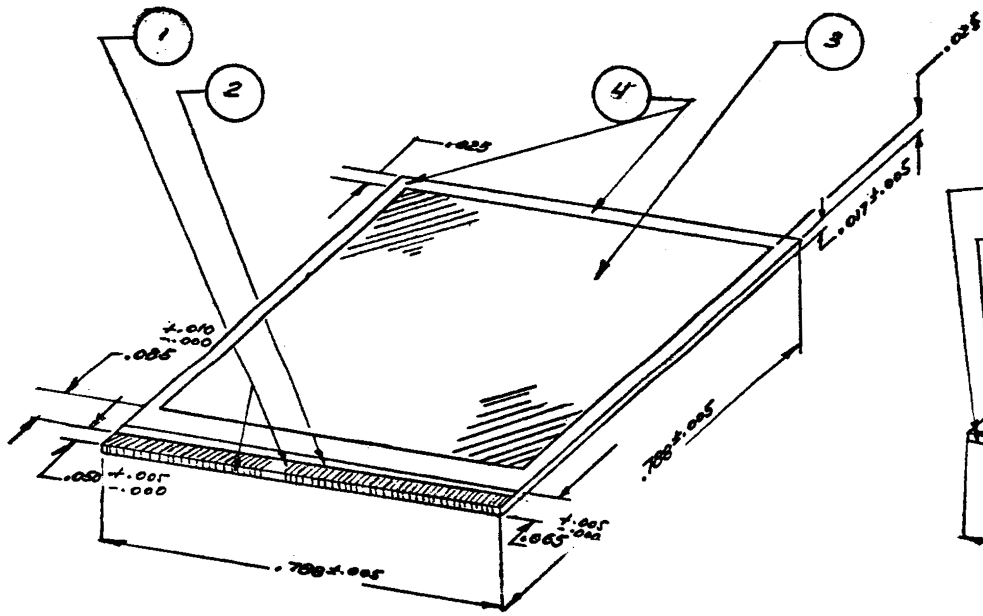
1. Lower cost (making sub-assemblies and panels).
2. More flexibility in achieving series parallel connections.
3. The ability to use a single large optically coated cover glass over many cells.
4. Large arrays (ft.^{2}) are possible in a single operation.
5. More power for the same size array.
6. Flexibility of the module permits the fabrication of large deployable solar arrays.

II. DISCUSSION

A. Cell Fabrication

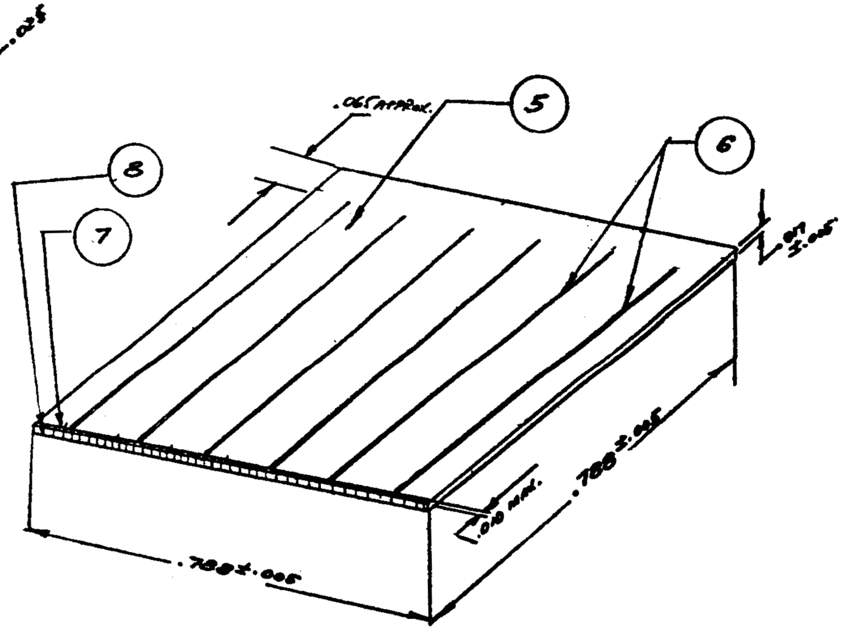
The evaluation of three processing techniques for the wrap-around cell, the physical configuration of which is shown in Fig. 1, were required at the start of the program. Two processes (Variation I and II) were identical except in the method of keeping the n/p junction from being shorted by the metallic contact material. Variation I provided a mask over the exposed junction (on the back of the cell) during evaporation of the contacts. Thus, no metal was deposited in this region. Variation II had metal evaporated over the entire back. Then, with all other areas protected, the metal was etched off a small area extending the width of the cell and consequently separating the n and p contacts. Variation I was found to be most satisfactory from a fabrication point of view and the cells for module assembly were fabricated using this method.

A third variation was constructed using silicon dioxide as a diffusion



N & P Side of Cell

1. Ti-Ag sintered contact on N region
2. Void area
3. P-contact
4. "Picture Frame" around 3 sides of cell



N Side of Cell

5. N-sensitive area
6. Conventional grid lines (.004 $\pm$ .001)
7. Connecting assurance bus bar
8. Ti-Ag contact evaporated & sintered over N region of cell

Fig. 1. Wrap-Around Solar Cell

mask. The SiO_2 was used to protect the desired p region on the back of the solar cell from being diffused. After diffusion of the n layer, the SiO_2 was removed and the contacts were evaporated in the same manner as Variation I. The aforementioned process should ultimately be used to construct the wrap-around cells. During this program, however, the growth of the SiO_2 at high temperatures (1100^{o}) caused a lowering of the lifetime in the p starting wafer. This resulted in a lower output than the cells of Variation I and consequently these cells were not used in the modularization. After the cell program had been completed, it was found that new methods for growing SiO_2 at low temperatures (200-300°C) had been developed. Future programs involving the wrap-around techniques should re-evaluate the SiO_2 masking because it appears to have the ultimate lowest cost potential.

Volt-ampere characteristics of thirty cells, ten made with each processing variation were measured at temperatures of -40, 0, 25, 75, 100, and 125°C A set of typical curves for one of each type of cell variation are given in Figures 2, 3, and 4.

B. Module Fabrication

After Variation I was chosen as the cell for modularizing, a pilot run was started to fabricate the required 200 cells. Simultaneously, substrate samples were being obtained and evaluated. An attempt was made to get the five substrate materials listed below:

1. H film with silver mesh bonded to it.
2. Mica with silver sputtered on it.
3. Epoxy filled fiber glass with silver mesh bonded to it.
4. Epoxy filled fiber glass with copper bonded to it.
5. Epoxy filled fiber glass with silver evaporated on it.

The H film-silver mesh combination could not be obtained. Mica with sputtered silver was evaluated and it was determined that the silver was too thin and would be scavenged off the substrate during soldering. The silver evaporated on epoxy filled fiber glass came off the substrate when exposed to soldering temperatures. Thus, only the epoxy filled fiber glass with silver and copper bonded to it were adequate. The copper was bonded as a solid sheet and then the pattern was etched into it. The silver was bonded as a mesh. This proved to be impractical because the epoxy bonding material

Type 2cm x 2cm wrap-around
Serial No. I-6
Date 10/14/64
Temperature as indicated °C
Tungsten, 100 mw/cm^2
Filter 3 cm H_2O, 1/2" Plexi.

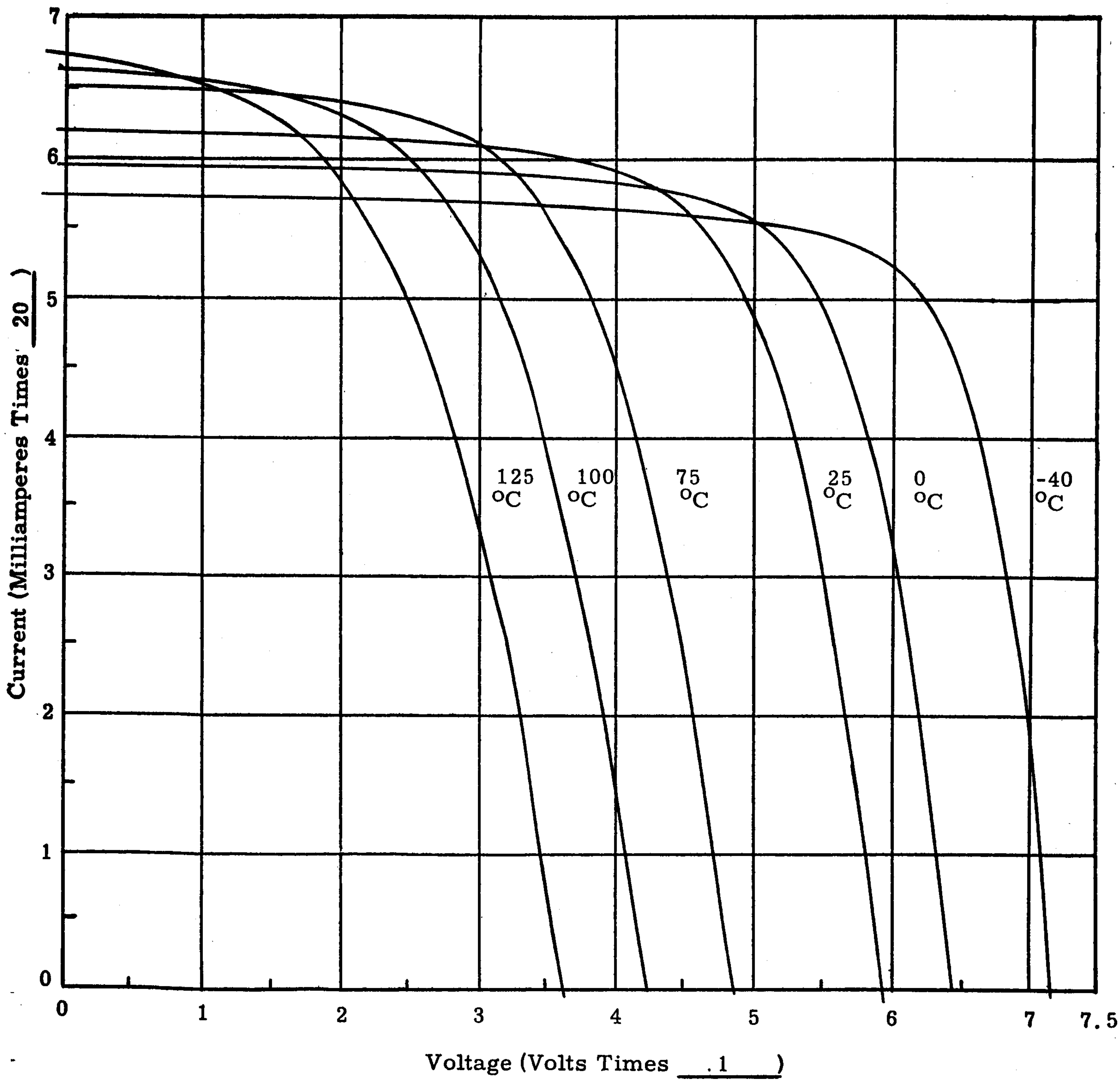


Fig. 2. RCA N/P Silicon Solar Cell Current-Voltage Characteristics

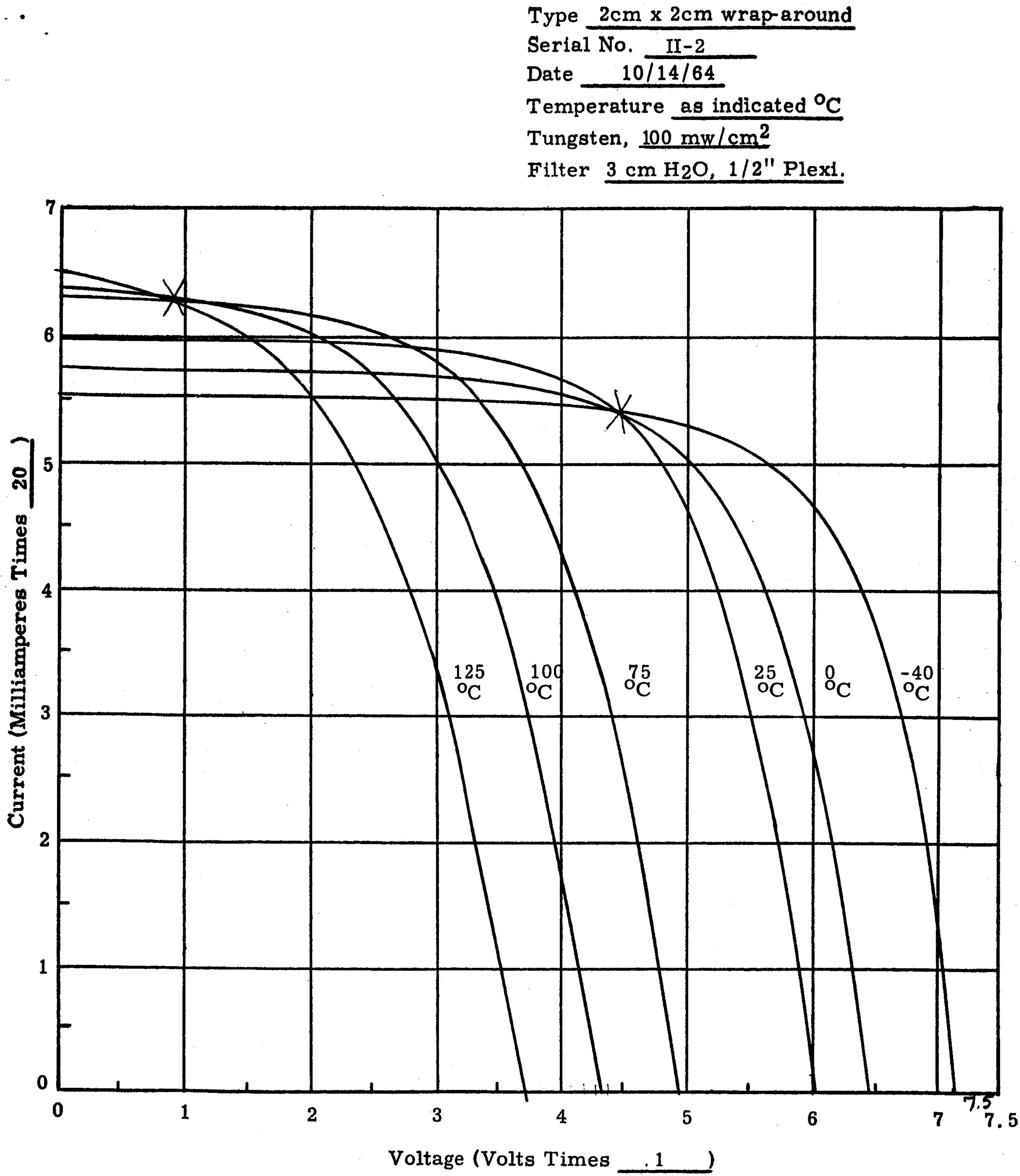


Fig. 3. RCA N/P Silicon Solar Cell Current-Voltage Characteristics

Type 2cm x 2cm wrap-around
Serial No. III-8
Date 10/14/64
Temperature as indicated °C
Tungsten, 100 mw/cm²
Filter 3 cm H_2O, 1/2" Plexi.

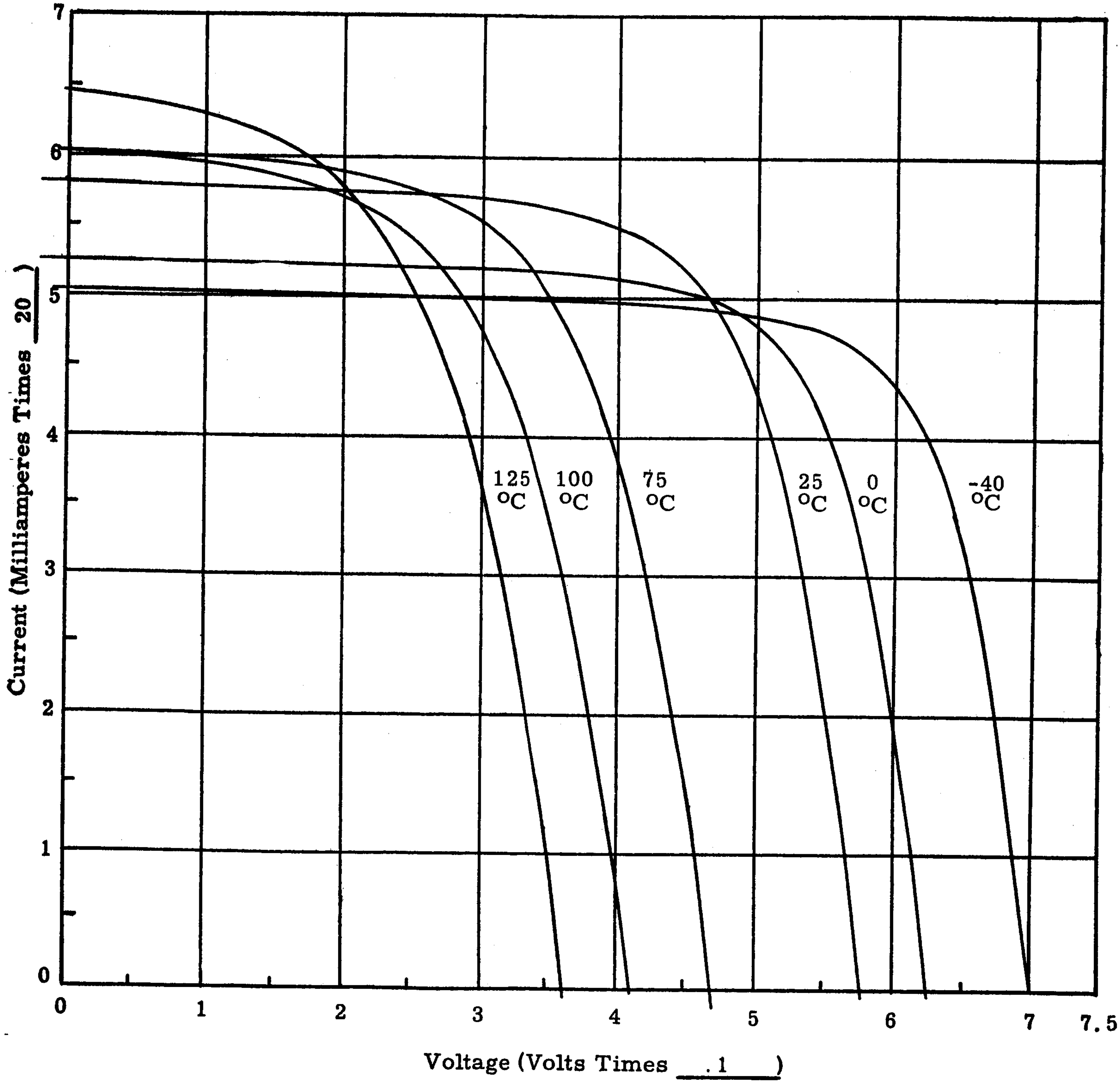


Fig. 4. RCA N/P Silicon Solar Cell Current-Voltage Characteristics

oozed up through the openings in the mesh and covered the top surface. Consequently, the desired patterns could not be etched in the mesh without abrasive action on the surface to remove the epoxy. Future programs should require all metals to be bonded as a solid sheet and patterns etched as required.

Twenty 10 cell modules were fabricated (see Fig. 5). The modules were constructed by jigging ten cells, simultaneously, in position over the metal interconnecting strips that were part of the substrate. The assembly was placed on a hot plate and the n and p connections of each cell was sweated to the proper connection strip. Thus, all connections were made at one time.

Ten of the twenty completed modules were subjected to twenty-five thermal cycles from $-78.5^{\circ}C$ to $+60^{\circ}C$. Volt-ampere characteristics were determined at 0, 5, and 25 cycles and at 100 and 140 mw/cm^2 intensity. The results of these measurements are given in Tables 1, 2, and 3.

A typical volt-ampere curve for a module is given in Fig. 6.

Thirty wrap-around cells and 20 completed modules were delivered to NASA at the completion of the program.

Figure 7 shows a drawing of the cell test fixture.

III. CONCLUSIONS

The material presented in this report shows that the construction of a wrap-around cell (both contacts on the back) is quite practical. Also, due to the increase in area (5%) of the active surface of the cell, increase power output (5% max.) for the same occupied area can be obtained. The use of these cells in the construction of modules employing printed circuit substrates has been further demonstrated. The efficiencies indicated for these modules (Tables 1, 2, and 3) are slightly higher (.4% - taking into account active area) than a module constructed of standard cells, such as the Nimbus type. Examination of the power output shows an increase above the Nimbus type module. The increase in power is not all due to efficiency increase. In fact, the power output of the wrap-around module is 4% higher than the Nimbus type after all factors have been taken into account. This is close to the expected 5% increase because of the 5% additional area.

Problems with substrates were encountered. This area should be investigated to determine the best substrate arrangement considering weight as well as bonding strength of metals.

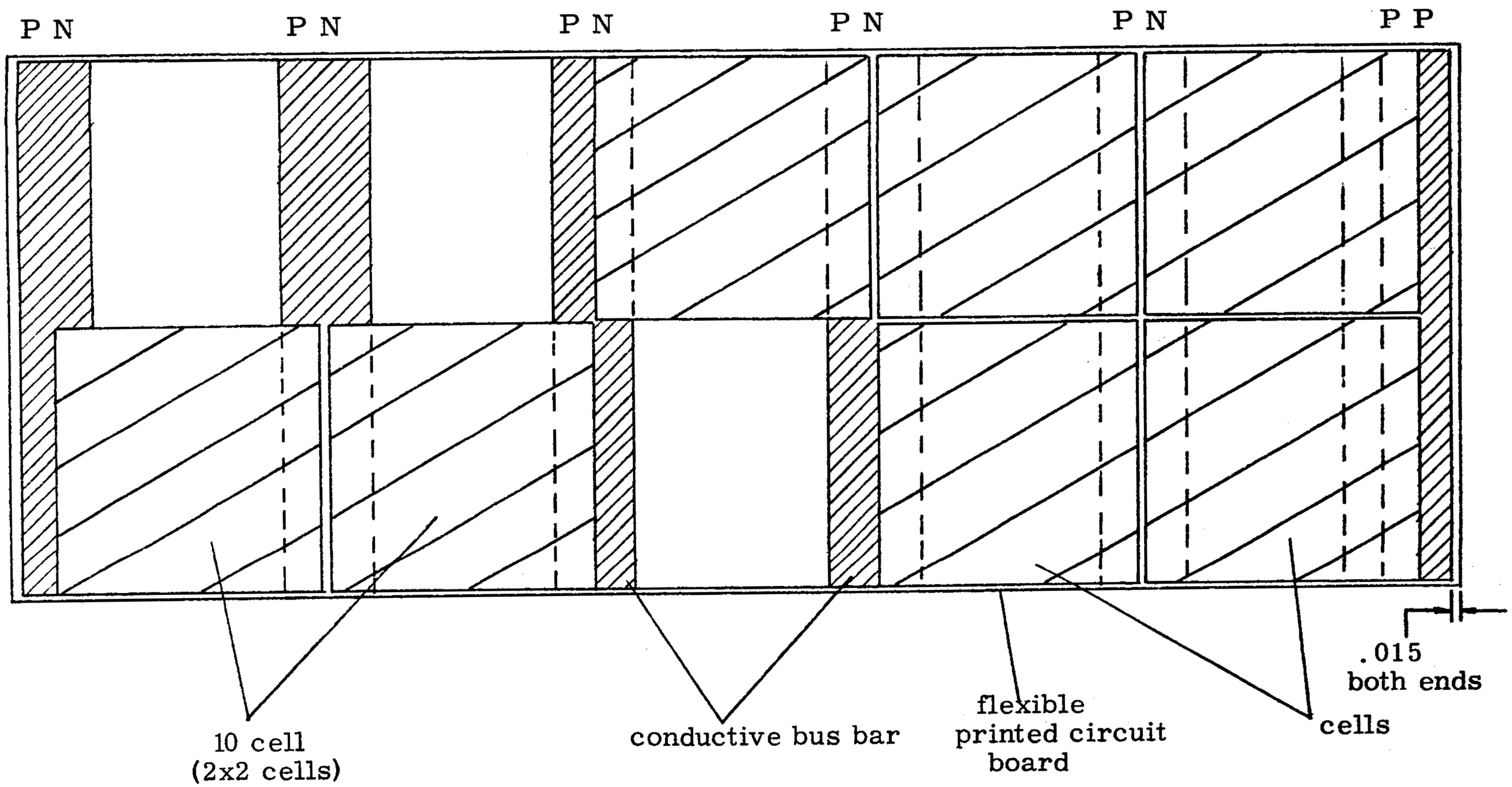


Fig. 5. Ten Cell Module

Table 1

WRAP-AROUND MODULES

INITIAL READINGS PRIOR TO THERMAL CYCLING

140 mw

AM = 0 Equivalent

Module No.	I_{sc} ma	V_{oc}	I_{mp}	V_{mp}	Eff.	Power Output mw
10C	290	3.01	263	2.34	11.0	615
11C	294	2.99	263	2.32	10.9	610
12C	295	2.99	264	2.3	10.8	607
13C	302	3.01	267	2.32	11.1	619
14C	296	3.02	266	2.335	11.1	621
15C	299	3.02	268	2.34	11.2	627
16C	298	3.01	266	2.305	10.9	613
3S	290	3.00	256	2.335	10.7	598
4S	293	3.005	263	2.31	10.8	608
5S	286	3.01	256	2.335	10.7	598
Avg.	294.3	3.05	263.2	2.32	10.9	612

100 mw

AM = 1 Equivalent

10C	243	2.985	220	2.35	12.9	517
11C	245	2.98	220	2.34	12.9	515
12C	247	2.98	218	2.335	12.7	509
13C	252	2.98	223	2.32	12.9	517
14C	248	2.995	222	2.34	13.0	519
15C	250	2.995	225	2.34	13.2	527
16C	249	2.99	222	2.335	13.0	518
3S	243	2.975	213	2.34	12.5	498
4S	244	2.98	223	2.31	12.9	515
5S	240	2.985	212	2.37	12.6	502
Avg.	246	2.985	220	2.34	12.9	514

Table 2

WRAP-AROUND MODULES

AFTER 5 THERMAL CYCLES OF -78.5°C to +60°C

140 mw

AM = 0 Equivalent

Module No.	I_{sc} ma	V_{oc}	I_{mp}	V_{mp}	Eff.	Power Output mw
10C	290	3.01	264.5	2.33	11.0	615.0
11C	293	3.0	262	2.34	11.0	612
12C	295	3.02	264	2.32	11.0	613
13C	302	3.00	268	2.31	11.1	618
14C	296	3.01	266	2.33	11.1	617
15C	299	3.02	268	2.34	11.2	626
16C	299	3.02	268	2.33	11.1	622
3S	292	3.01	257	2.34	10.8	601
4S	295	3.01	267	2.30	11.0	613
5S	290	3.01	260	2.32	10.8	602
Avg.	295	3.01	264	2.33	11.0	614

100 mw

AM = 1 Equivalent

10C	242	2.99	219	2.37	13.0	518.0
11C	246	2.99	219	2.35	12.8	514
12C	247	3.00	220	2.35	12.9	517
13C	252	2.99	224	2.33	13.0	520
14C	248	2.99	222	2.35	13.0	521
15C	250	3.00	225	2.34	13.2	527
16C	250	2.99	224	2.33	13.0	520
3S	243.5	2.99	214	2.35	12.5	502
4S	246	2.99	222	2.34	12.9	517
5S	242	3.00	215	2.35	12.6	505
Avg.	247	2.99	220	2.35	12.9	526

Table 3

WRAP-AROUND MODULES

AFTER 25 THERMAL CYCLES OF -78.5°C to +60°C

139.6 mw

AM = 0 Equivalent

Module No.	I_{sc} ma	V_{oc}	I_{mp}	V_{mp}	Eff.	Power Output mw
10C	291	3.01	262	2.325	10.9	609
11C	296	3.05	267	2.33	11.1	622
12C	298.5	3.01	268	2.30	11.0	616
13C	304.5	3.015	270	2.315	11.2	625
14C	299.5	3.015	268.5	2.325	11.1	624
15C	300	3.015	266	2.325	11.0	618
16C	300.5	3.015	264	2.315	10.9	611
3S	294	3.10	258	2.34	10.8	604
4S	296	3.10	266	2.30	10.9	612
5S	290	3.05	259	2.33	10.8	603
Avg.	297	3.04	265	2.32	11.0	614

100 mw

AM = 1 Equivalent

Module No.	I_{sc} ma	V_{oc}	I_{mp}	V_{mp}	Eff.	Power Output mw
10C	243	2.995	222.5	2.365	13.2	526
11C	246.5	2.99	221	2.35	13.0	519
12C	249.5	2.995	221	2.35	13.0	519
13C	253	2.995	225.5	2.335	13.2	527
14C	249.5	3.00	224	2.35	13.2	526
15C	251.5	3.00	225.5	2.35	13.2	530
16C	251	3.00	226.5	2.325	13.2	527
3S	244	2.995	215	2.35	12.6	505
4S	246	2.99	221.5	2.33	12.9	516
5S	241.5	2.995	216	2.345	12.7	507
Avg.	248	3.00	222	2.35	13.0	520

Type module wrap-around
Serial No NAS5-3812-8C
Date Nov. 1964
Temperature 25°C
Light Source: Tungsten
/008/40 mw/cm²

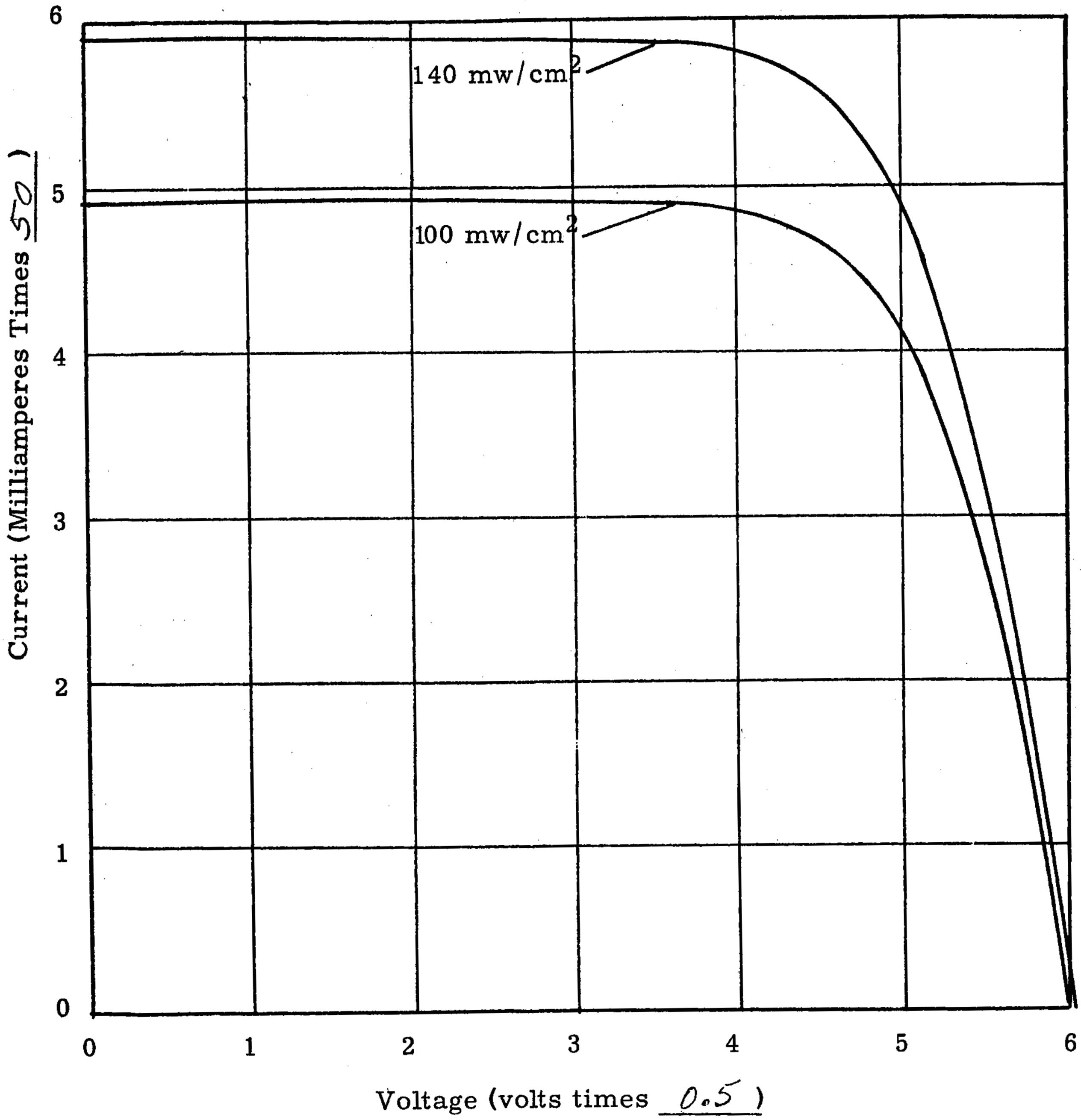
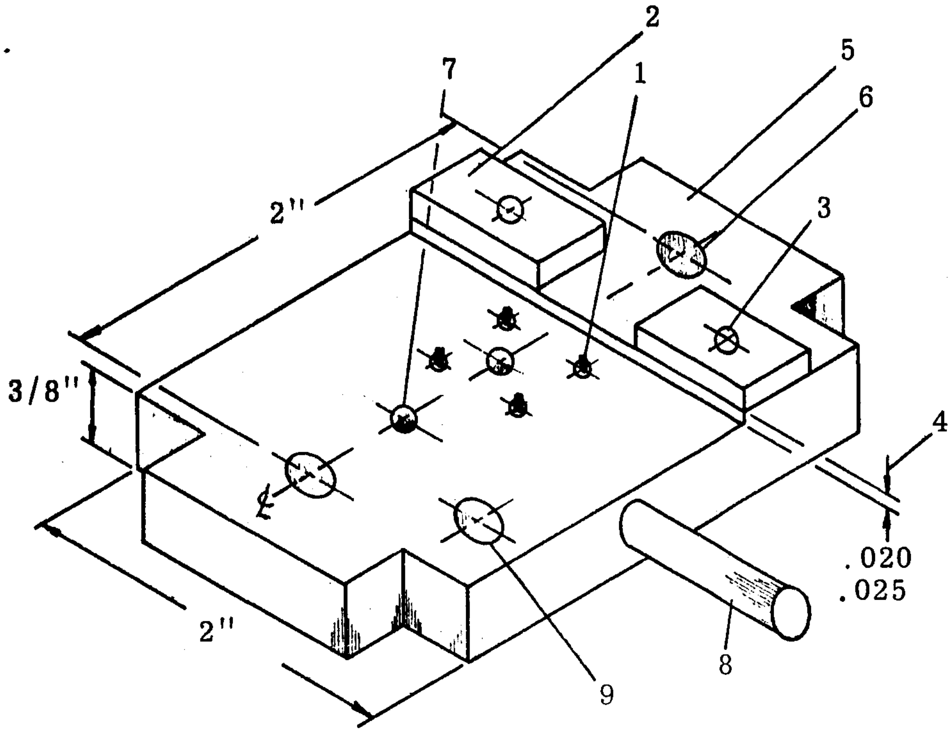


Fig. 6. RCA N/P Silicon Solar Cell Current-Voltage Characteristics



1 — (4) spring loaded S. S. probes (see assembly detail)
2 — boron nitride stops (2)
3 — clearance holes for (2) #4-40 Allen heads screws
4 — distance between ℄ of probes and stops
5 — brass block
6 — (2) clearance holes for #8-32 screws
7 — holes (2) for vacuum
8 — vacuum inlet nozzle
9 — threaded hole to secure thermocouple to the block

Not to Scale

Probe Assembly

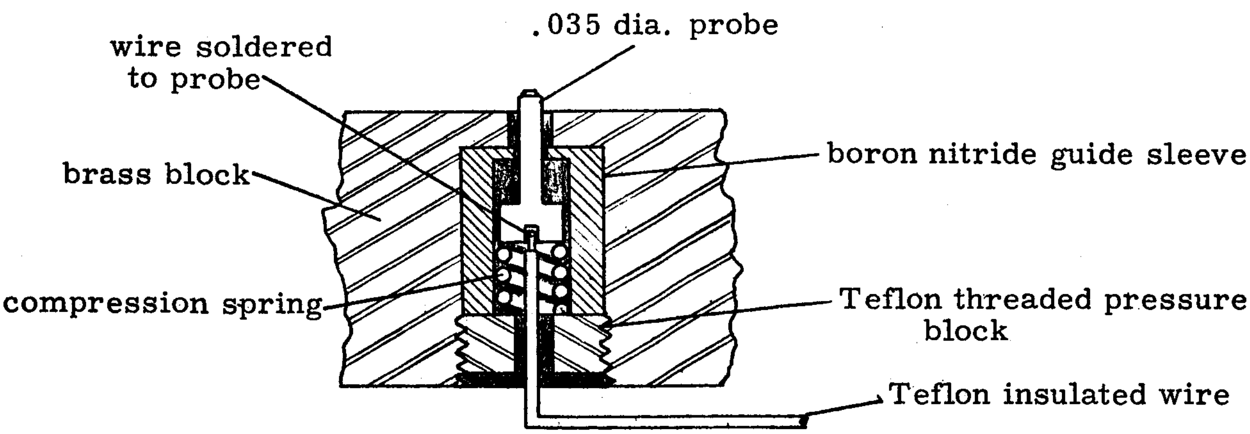


Fig. 7. Test Jig for Wrap-Around Cell

The success of this cell and module program indicates that the fabrication of large arrays ($ft.^2$) is quite feasible. Thus, the advantages, cited earlier, appear to be quite plausible.

IV. RECOMMENDED PROGRAM FOR FUTURE WORK

1. To fabricate pilot production quantities (1000-2000) of wrap-around cells whereby tooling costs, manufacturing costs, production yield, and distribution of cell efficiencies can be established.
2. To optimize modularization material and technique.
3. To fabricate demonstration panels for environmental testing.
4. To develop and fabricate wrap-around cells with a maximum thickness of 0.008 inch.